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Single-institution comparative analysis for odontoid resection: posterior transaxis versus anterior transnasal approach

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OBJECTIVE The resection of an upwardly migrated odontoid is most widely performed via an anterior endoscopic endonasal approach after the addition of posterior occipitocervical instrumentation. In patients with craniovertebral junction (CVJ) anomalies like basilar invagination (BI), surgery is usually achieved in two separate stages. However, the authors have recently introduced a novel posterior transaxis approach in which all the therapeutic goals of the surgery can be safely and effectively accomplished in a single-stage procedure. The aim of the current study was to compare the widely used anterior and the recently introduced posterior approaches on the basis of objective clinical results in patients who underwent odontoid resection for BI.

METHODS Patients with BI who had undergone odontoid resection were retrospectively reviewed in two groups. The first group (n = 7) consisted of patients who underwent anterior odontoidectomy via the standard anterior transnasal route, and the second group (n = 6) included patients in whom the novel transaxis approach was performed. Patient characteristics, neurological conditions, and modified Rankin Scale (mRS) scores at admission were evaluated. Operative time, changes in intraoperative neurophysiological monitoring, blood loss during surgery, odontoid resection rate, postoperative complications, and mortality were compared between the patient groups.

RESULTS Data were retrospectively reviewed for 13 patients who underwent odontoid resection, posterior CVJ decompression, and occipitocervical instrumentation at the Ankara University School of Medicine Department of Neurosurgery between 2009 and 2022. In the first group (n = 7), patients who underwent anterior odontoidectomy via the standard endonasal route, two serious complications were observed, pneumocephaly and basilar artery injury. In the second group (n = 6), patients in whom the novel transaxis approach was performed, only one complication was observed, occipital plate malposition.

CONCLUSIONS This study represents the results of what is to the authors' knowledge the first comparison of a novel approach with a widely used surgical approach to odontoid resection in patients with BI. The preliminary data support the successful utility of the transaxis approach for odontoid resection that meets all the operative therapeutic demands in a single-stage operation. Considering the diminished surgical risks and operative time, the transaxis approach may be regarded as a primary approach for the treatment of BI.

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KEYWORDS odontoidectomy; endoscopic transnasal approach; transaxis; basilar invagination; craniovertebral junction anomalies

Basilar invagination (BI), which is associated with craniovertebral junction (CVJ) and cervical anomalies, constitutes a major health issue because of brainstem and spinal cord compression related to narrowing of the spinal canal and foramen magnum by protrusion of the odontoid process through the space. The primary treatment goals in such patients consist of decompression of the brainstem and upper cervical spinal cord as well as correction of cervical alignment. The invaginated and posteriorly displaced odontoid process in BI is the primary

ABBREVIATIONS BI = basilar invagination; CR = complete resection; CVJ = craniovertebral junction; IR = insufficient resection; mRS = modified Rankin Scale; PEG = percutaneous endoscopic gastrostomy; SCR = subcomplete resection.

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related pathology that leads to neural injury. Furthermore, the surgical removal of the odontoid process increases the degree of existing instability.[1,2]

The most commonly used surgery in such cases consists of two stages, initial posterior craniocervical fusion and suboccipital craniectomy in the first stage and cervical laminectomy followed by transnasal odontoidectomy in the second separate stage.[3] The resection of the upwardly migrated odontoid is most widely performed via an anterior endoscopic endonasal approach. However, recent improvements in surgical techniques and developments in surgical technology have enabled neurosurgeons to design and utilize a shorter and more practical all-in-one approach with less morbidity and mortality.[4] Recently, a novel posterior midline approach, with its revised current name, the transaxis approach, has been introduced in which all the therapeutic goals are safely and effectively accomplished in a single-stage surgical procedure.[5]

The aim of the current study was to compare the most widely used anterior endonasal approach with the posterior transaxis approach to odontoid resection on the basis of objective clinical results in patients who underwent surgical treatment of BI.

Methods

Medical records were reviewed for all patients with BI who underwent odontoid resection between 2009 and 2022 at the Ankara University School of Medicine Department of Neurosurgery. Informed consent was obtained from patients before the surgical procedures. The study was approved by the institutional ethics board. To maintain standardization during evaluation, patients with CVJ pathologies rather than BI and patients with missing inpatient data or follow-up data were excluded.

Patients were retrospectively reviewed in two groups, according to the chosen surgical approach. Patient characteristics, neurological examination results, and modified Rankin Scale (mRS) scores at admission were evaluated. Operative duration, changes in intraoperative neurophysiological monitoring parameters, blood loss during surgery, odontoid resection rate, postoperative complications, mortality, postoperative mRS, and 2-month postoperative follow-up results were compared between the two groups. The technical principles, nuances, and steps of these two approaches are explained in detail in previously published related articles.[5,6] Nonetheless, because the transaxis approach presents a novel corridor for odontoidectomy, the important key points of this technique are reemphasized here, and the operative nuances are highlighted briefly in this section to increase the comprehensibility of this approach.

Following fixation of the head with the patient in a prone position under general anesthesia and registration of an intraoperative CT-based neuronavigation system, the suboccipital and upper cervical regions are exposed using a posterior midline skin incision. A suboccipital craniectomy and removal of the posterior arch of the atlas are completed initially. The point at which the lateral part of the upper margin of the lamina connects with the lateral mass of the axis above the pedicle is identified, and all the soft tissue is removed. Then, with the aid of the neuronavigation system, the surgical trajectory to the odontoid is determined at this key point. Then, bone removal is performed along the designated direction to create an optimal surgical cavity under the microscope that allows the introduction of the endoscope. A neurosurgical sponge and fibrin glue may be used to control bleeding from the large dilated venous plexus and restore hemostasis. In some cases, the root of the second cervical nerve may restrict visualization of the entire cavity and may require spinal cord retraction. In this case, sacrifice of this nerve will create additional surgical freedom. According to our intraoperative observations, endoscope-assisted odontoidectomy can be performed either bilaterally or unilaterally.

All operations were performed in the same institution. Resection of the odontoid was considered complete resection (CR) when there was no obvious visible odontoid process on postoperative MRI and CT. With subcomplete resection (SCR), CSF flow was allowed and decompression of the brainstem and spinal cord was achieved regardless of the odontoid removal rate. The resection was considered an insufficient resection (IR) in cases in which odontoid compression was still observed.

Results

Between 2009 and 2022, 13 fully documented patients with a median age of 38 years diagnosed with BI (8 male and 5 female patients; 1 pediatric patient aged 9 years and 12 adult patients) were included in the study. Patient preoperative primary symptoms, neurological examination results, pre- and postoperative mRS scores, secondary preoperative conditions if a secondary operation occurred, and postoperative clinical conditions are shown in Table 1.

General symptoms were grouped as headache, numbness of the lower and upper extremities, swallowing difficulties, and speech impairments, and the neurological examinations revealed a wide range of physical signs, from hemiparesis, hemihypoesthesia, dysphagia, ataxia, and the presence of pathological reflexes (Hoffman reflexes in 2 patients) to no neurological deficits. Patient mRS scores were evaluated with regard to their level of disability, ability to carry out previous activities, and need for support in tasks of everyday living.

Patients who underwent anterior transnasal odontoidectomy surgery received initial occipitocervical instrumentation while in the Concorde position during the first stage and were then repositioned to supine at the second stage for transnasal odontoidectomy. Patients who underwent posterior transaxis odontoidectomy surgery were placed in the Concorde position and remained in this position throughout all steps of the surgery. In both groups, odontoidectomy was performed with a rigid neuroendoscope guided by a neuronavigation system. In contrast to the first group, radiological images of patients in the second group were registered using an intraoperative CT (Airo mobile CT scanner, model number MobiCT-32, Mobius Imaging) as part of the neuronavigation system (Brainlab AG). In addition to this initial CT imaging, patients in this group underwent a second intraoperative CT scan to evaluate the odontoid resection rate intraoperatively, and a third scan

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TABLE 1. Detailed data regarding patient characteristics in each group

Pt No.	Age (yrs)	Sex	Dx	Preop Sx	Neuro Exam	mRS Score*	Op (hrs)†	Blood Trans	Intraop Neuromonitoring	Periop Complications	Odon Resect	FU mRS Score‡	Postop 2-Mo FU	Stay (days) §
Group 1 (anterior transnasal odontoidectomy)														
1	45	M	BI	Gait imbalance, lt hemiparesis	Lt hemiparesis (3/5), impaired gag reflex, lt-hand Hoffman sign	1	3/3	1 unit at 1st op	Slight lt SEP response improved after 2nd op	None	CR	0	Gait & hemiparesis improved, w/o recurrence	24
2	30	F	BI	Impaired speech, swallowing difficulty	Dysphagia, disarticulation, swallowing difficulty	1	3.5/3	None	Rt SEP & MEP responses lost	BA pseudoaneurysm, endovascular arterial embolization, rt hemiparesis, labored breathing, tracheostomy, prolonged hospitalization	CR	4	Pt bedridden, w/ PEG tube	38
3	42	F	BI	Neck & rt arm pain	Intact	1	3.5/3	None	No specific difference	None	CR	0	Sx relief	8
4	16	M	BI	Neck pain, swallowing difficulty, UE numbness	UE hypoesthesia, disarticulation, & bilat Hoffman sign	1	6/2.5	1 unit at 1st op	No specific difference	Trouble swallowing, screw malposition	CR	0	Sx relief	31
5	65	F	BI	HA, bilat LE numbness, swallowing difficulty	Ataxia, impaired gag reflex, dysfunction	1	3/2.5	None	Slight SEP response improved on UEs after 2nd op	None	CR	0	Swallowing difficulty & numbness improved	54
6	16	M	BI	Neck pain, UE numbness	UE hypoesthesia, hyperactive tendon reflexes	1	6.5/4	1 unit at 1st op	No specific difference	Pneumocephalus	CR	0	Gait & hemiparesis improved, no recurrence	14
7	40	M	BI	Imbalance, neck pain	Trunk ataxia, hyperactive tendon reflexes	1	3/3	None	No specific difference	None	CR	0	Balance & gait improved, no recurrence	8
Group 2 (transaxis approach)														
1	49	F	BI	Neck & lt arm pain	Tetraparesis (4/5), hyperactive tendon reflexes	2	3	None	Improved SEP response hemiparetic side	None	CR	0	Hemiparesis & gait improved	9
2	9	M	BI	Neck pain & lt arm monoparesis	Lt arm hemiparesis (3/5), hyperactive tendon reflexes	2	3	None	Improved SEP response hemiparetic side	Occipital plate malposition, transient C5 nerve palsy	CR	0	Hemiparesis & gait improved	8
3	85	M	BI	Acute tetraparesis	Tetraparesis (4/5), hyperactive tendon reflexes, impaired gag reflex	3	4	2 units	Slight lt-side SEP response emergence	None	CR	1	Hemiparesis & gait improved	10

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TABLE 1. Detailed data regarding patient characteristics in each group

Pt No.	Age (yrs)	Sex	Dx	Preop Sx	Neuro Exam	mRS Score*	Op (hrs)†	Blood Trans	Intraop Neuromonitoring	Periop Complications	Odon Resect	FU mRS Score‡	Postop 2-Mo FU	Stay (days) §
4	36	M	BI	Neck & bilat leg pain	Rt hemiparesis (4/5), hyperactive tendon reflexes	1	4	None	Improved SEP response hemiparetic side	None	SCR	1	Hemiparesis & gait improved	5
5	26	M	BI	Neck pain & lt arm numbness	Lt arm hypoesthesia, trunk ataxia	1	3	None	Global improved SEP response	None	CR	0	Hemiparesis & gait improved	8
6	38	F	BI	Acute tetrapa-resis	Tetraparesis 4/5, hyperreflexia, hyperactive tendon reflexes, impaired gag reflex	2	3	None	Global improved SEP response	None	SCR	0	Hemiparesis & gait improved	4

BA = basilar artery; Dx = diagnosis; FU = follow-up; HA = headache; LE = lower extremity; MEP = motor evoked potential; Neuro = neurological; Odon Resect = odontoid resection; pt = patient; SEP = somatosensory evoked potential; Sx = symptoms; Trans = transfusion; UE = upper extremity.

* mRS score at admission.

† Duration of operation. The duration of each stage is given for the patients in group 1.

‡ mRS score at the final follow-up.

§ Length of stay in the hospital.

for investigation of the operative field, efficiency of the procedure, and position of the posterior occipitocervical construct at the final part of the operation.

In the first patient group, 3 patients needed consecutive surgeries because of perioperative complications. One patient needed re-exploration and revision of the lateral mass screws, 1 patient had skull base repair after pneumocephalus, and the third patient had an iatrogenic injury of the basilar artery requiring subsequent endovascular arterial coiling.[7] This patient, who also developed a hemothorax in the operating room after intubation and received a percutaneous endoscopic gastrostomy (PEG), was discharged without tracheostomy or mechanical ventilation support but remained bedridden at the time of this report. For the remaining patients, the mRS scores remained at 0, and these patients were discharged without neurological deficits. The approximate operation duration was 6 to 7 hours because the anterior and posterior approaches were performed in different stages. The odontoid resection rates were determined by evaluation with postoperative CT scans, which confirmed CR in all cases.

In the second group, all patients underwent posterior transaxis odontoidectomy and occipitocervical instrumentation surgery at the same stage, and the approximate duration of the surgery was 3 to 4 hours. Five patients recovered without any complications or need for a second surgery. One patient had occipital plate malposition and transient fifth cervical nerve palsy. SCR of the odontoid was performed in 2 patients, and the remaining 4 patients had CRs. Postoperative mRS scores decreased to 0 in 4 patients and their symptoms improved postoperatively. Detailed data regarding complications and follow-up data are presented in Table 1. Pre- and postoperative radiological images of 2 sample cases are presented in Figs. 1–3.

Discussion

Craniocervical junction anomalies pose a high risk of mortality and morbidity because of instability and neural impairment. Although the treatment itself carries risks regarding pre- and postoperative complications, surgery is inevitably the first treatment option in such cases.[1,2]

Restoring CSF flow and relieving pressure on related critical neurovascular structures via craniocervical instrumentation, posterior fossa decompression, and odontoidectomy are the target-oriented steps of the surgery. However, choosing the best surgical approach for such complicated life-threatening pathologies remains a struggle given that the surgery must be performed in a narrow area that is crowded with critical neurovascular structures that limit surgical options.[3] Currently known and practiced surgical approaches to the craniocervical region include anterior transoral, posterior, and posterolateral approaches, which include the far lateral, extreme lateral, transatlas, and transcondylar approaches.[5] Such newly evolved surgical approaches (i.e., lateral, far lateral, extreme lateral) have tended to replace anterior to posterior approaches. The posterolateral approach has been used more frequently in cases requiring mobilization of the vertebral artery to decrease the risk of injury.[7] However, the transaxis approach does not require any vertebral artery transposition or ma-

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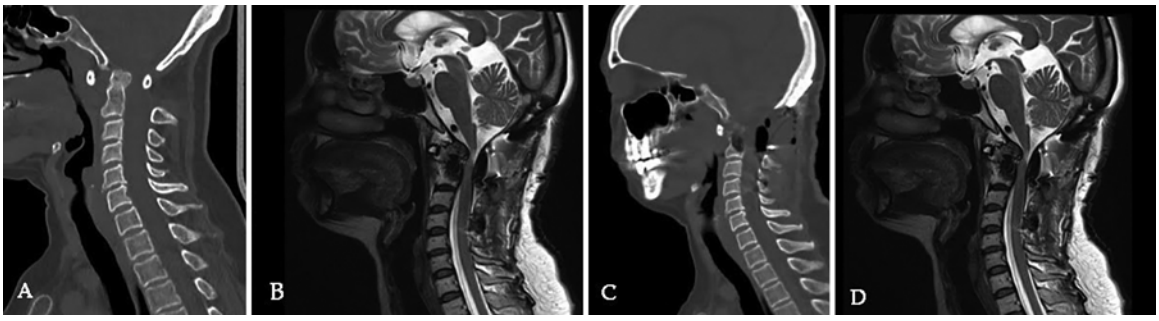


FIG. 1. Preoperative and postoperative sagittal CT scans (**A and C**) and MR images (**B and D**) obtained in a 49-year-old female patient who suffered from neck and left arm pain. Tetraparesis and hyperactive tendon reflexes were observed. This patient underwent surgery via the transaxis approach, and subcomplete odontoid resection was achieved. Note that the anterior arcus of the C1 vertebra was preserved.

nipulation. Far lateral and extreme lateral approaches are variations of the posterolateral approach that provide upper cervical and lateral exposure to the region.[7,8] The condylar, supracondylar, and paracondylar approaches used as variations of the far lateral approach enable the surgeon to perform more extensive bone resection to enlarge the surgical corridor.[7,9] The transcondylar approach defined by al-Mefty et al. provides a wide surgical corridor that aids the surgeon in performing both instrumentation and fusion of the craniocervical junction in the same session.[10] The transaxis approach helps the surgeon to access the odontoid process bilaterally and achieve posterior decompression and occipitocervical fusion in the same stage.[5] This approach also provides multidirectional exposure of the CVJ and the C1 and C2 vertebrae in a way that allows the neurosurgeon to relieve neural structure pressure circumferentially through a common access route. A key point and the initial step of this approach is identification of the C2 lamina and pedicle, as well as the junction of these two anatomical structures, and exposure of the inner, superior, and medial edges of the C2 lamina at this junction. The access route to the odontoid is created at this junction, and this crucial point should be considered a window to the operative cavity that allows simultaneous utilization of two surgical instruments, one of which is the endoscope. In complex cases in which the length of surgical instruments is not sufficient or spinal cord retraction is needed, the creation of operative windows may be required on both sides of the spinal cord with or without sacrificing the second cervical nerve in order to reach far and deep locations. In such cases, three-hand endoscope-guided odontoidectomy using bilateral working corridors should be applied rather than a unilateral transaxis approach. Visualization of the surgical cavity is important for avoiding penetration of the oropharyngeal space and predicting the odontoid removal rate. Following this phase, the next phases of the transaxis approach are enlargement of the region, introduction of surgical instruments, gradual deepening via bone resection, and finally, completing the odontoidectomy.

In the two-stage (anterior and posterior) surgery, during repositioning of the patient there is a high risk of dislocation between C1 and C2 because of their hypermobility and instability, with a resulting high risk of neural injury related to spinal canal obliteration due to unbounded excessive head movement. With the transaxis approach, however, possible complications and prolonged surgery related to repositioning are avoided. Thus, serious complications including pneumocephaly and basilar artery injury were observed in the patients who underwent two-stage surgery, whereas occipital plate malposition was the only complication in the group who underwent transaxis approach surgery.

Regarding the odontoidectomy, the most widely used approach is the transoropharyngeal approach, which was first described in 1917 by Kanavel. Then, in 1951, the use

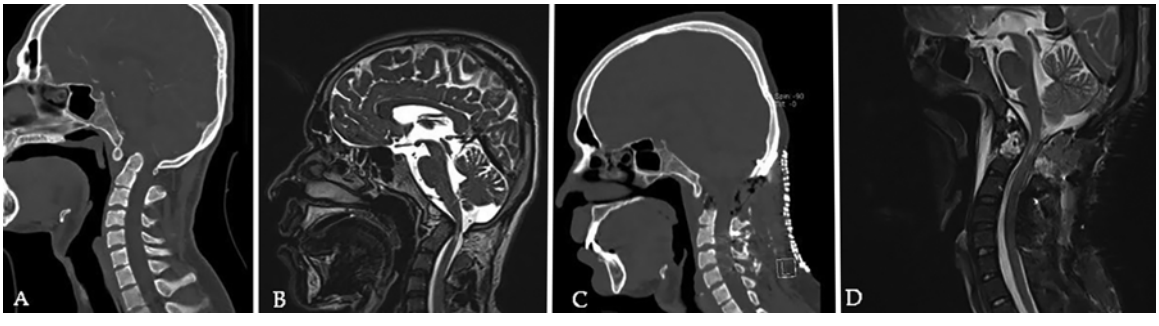


FIG. 2. Preoperative and postoperative sagittal CT scans (**A and C**) and MR images (**B and D**) obtained in a 26-year-old male patient who suffered from neck pain and numbness of the left arm. Hypoesthesia of the left arm and truncal ataxia were detected. This patient underwent surgery via the transaxis approach, and complete odontoid resection was achieved.

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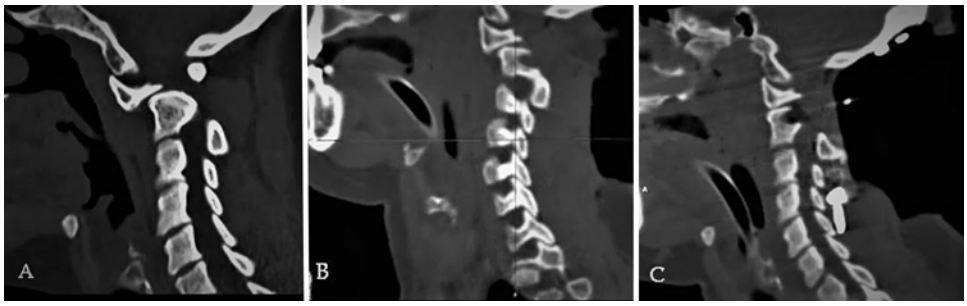


FIG. 3. A: Sagittal view of an initial intraoperative CT scan showing facets that represent preoperative alignment indicating atlantoaxial facetal dislocation. **B:** Sagittal view of a second intraoperative CT scan showing instability and facetal joint dislocation after suboccipital craniectomy, C1 posterior arcus removal, and partial odontoidectomy. **C:** Sagittal view of a third intraoperative CT scan showing final alignment after complete odontoidectomy and occipitocervical stabilization.

of this approach for odontoid process resection was reported by Scoville and Sherman.[11,12] The mortality rate of odontoidectomy was suggested to be as high as 2% to 8% in some studies.[13] This rate has been decreased with the help of recent developments in intraoperative imaging systems and monitorization.[4] However, this type of approach is still associated with complications and morbidity burdens such as CSF fistula and leakage, meningitis or mediastinitis, and subluxation, as well as the prolonged need for nasogastric tube feeding and prolonged hospitalization.[7,14] Anterior wall laceration of the oropharynx during surgery via the transoropharyngeal approach, although it did not occur in the reported series, is a major potential complication with heavy morbidity burden during such surgery. Also, as was mentioned above, the basilar artery might be at high risk during surgery via the anterior transnasal endoscopic approach. However, none of our patients who underwent posterior transaxis odontoidectomy needed additional transoral surgery, although ventral decompression was suggested and is known to be effective. This technique provides sufficient decompression and odontoid resection with the same posterior approach for occipitocervical fusion. Although the statistical significance of this finding could not be analyzed because of the limited number of patients, the length of hospitalization was shorter in the second than the first patient group, which is an important issue with regard to choosing the most cost-effective approach.

Since we reported our first description of the posterior transaxis approach, our case series and surgical experience have gradually progressed. Consequently, we have become more familiar with the pathoanatomical configuration of the CVJ region in BI patients. Considering the location of the normal odontoid process, without any CVJ or odontoid pathology, reaching the odontoid during surgery is known to be difficult even with spinal cord mobilization and longer instruments. What makes our approach effective and feasible is that a dislocated and backward-protruding odontoid process creates its own surgical cavity and shortens the access distance. When we first suggested and published this approach, we named it the "posterior midline cervical approach."[5] Recently, when we considered that during the exposure of the inner, medial, and superior edges of the C2 lamina, just at the junction of the C2 lamina and pedicle, and the path from this point to the odontoid, our starting point was the second cervical vertebra, the axis, we concluded that naming this surgical technique the "transaxis approach" would be both descriptive and appropriate.

No rigid consensus has been established for approaching craniocervical junction pathologies. Every approach holds its own beneficial aspects and complication risks. The choice of approach should be made based on the nature of the pathology and the anatomical complexity of the surgical corridor, results of preoperative imaging, and experience of the neurosurgeon. The transaxis approach for odontoid resection seems feasible in that all surgical goals are achieved in a single stage. In addition, the fact that we have become proficient and experienced in performing all the techniques mentioned above increases the value of our subjective comments regarding the pros and cons for each approach.

Regarding the limitations of this study, the use of intraoperative CT, which might not be available in all centers, is suggested for guidance during odontoid resection. Also, the availability of neuroendoscopy might be another limitation. Because the anterior transnasal approach was employed earlier in the study interval, the related cases seem to have had longer follow-up periods than the posterior transaxis cases, which may be considered as a potential time-dependent bias. However, in all the cases in both groups the surgery was performed with the guidance of neuronavigation systems. The necessity of sacrificing the second cervical nerve root to gain extra working space and a surgical corridor is another potential stricture of this technique. However, with the advances of our technique, sacrificing the second cervical nerve was not required in the last 2 patients of the series reported here. Further randomized studies with larger patient series are needed to validate the results of the present study.

Conclusions

CVJ surgery harbors serious potential complications because of increased spinal cord vulnerability related to decreased blood flow, hypoperfusion, and decreased neural integrity, and thus requires relatively fast surgery of short duration that is safe, precise, and effective. In this study, we performed what is to our knowledge the first comparison between one novel and another widely used

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surgical approach to CVJ surgery in patients with BI. The preliminary data support the success and utility of the transaxis approach for odontoid resection, a novel technique that meets all the operative therapeutic demands in just a single operative stage. Considering the diminished surgical risks and shorter operative time demonstrated in this study, the transaxis approach may be regarded among the primary available approaches to be chosen for use in patients with BI.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Doğan, Bayatli, Eray, Terzi, Eroglu, Ozgural, Kahilogullari. Acquisition of data: Doğan, Eray, Terzi, Hasimoglu, Tekneci, Beton, Ozgural, Kahilogullari, Caglar. Analysis and interpretation of data: Doğan, Bayatli, Eray, Erdogan, Terzi, Tekneci. Drafting the article: Doğan, Bayatli, Eray, Terzi, Eroglu, Ozgural, Kahilogullari. Critically revising the article: Doğan, Bayatli. Reviewed submitted version of manuscript: Doğan, Bayatli, Eray, Kahilogullari. Approved the final version of the manuscript on behalf of all authors: Doğan. Statistical analysis: Doğan. Administrative/technical/material support: Doğan, Bayatli, Eray, Ozgural, Caglar. Study supervision: Doğan, Eray, Hasimoglu, Beton, Eroglu.

Supplemental Information

Videos

Video Abstract. https://vimeo.com/797367459.

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